Booster Throughput Scenarios for KOPIO

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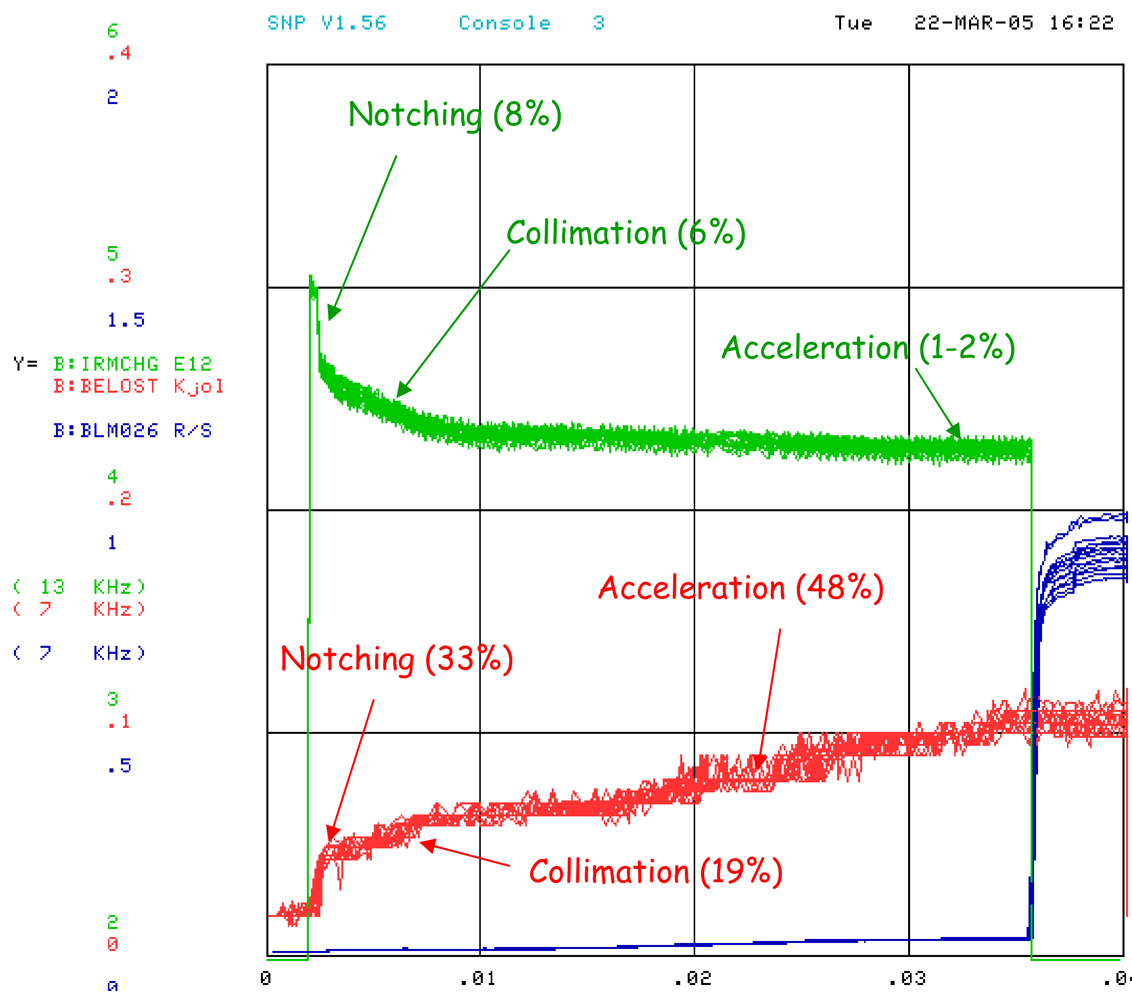
Booster Performance

- Amount of beam power lost per pulse is inversely proportional to the repetition rate

$$P_L = J_L R$$

- For simplicity the beam loss can be divided into two categories,
  - beam loss due to creating the beam gap (notch) for extraction
  - beam lost transversely during acceleration

$$J_L = E_n \Delta N_n + E_A \Delta N_A$$



Booster Performance

- The total efficiency of the Booster is:

$$\frac{N_{ext}}{N_{inj}} = \left(1 - f_n - f_A\right)$$

  - f_n is the ratio of the amount of beam loss during notching to the injection intensity
  - f_A is the ratio of the amount of beam loss during acceleration to the injection

- For a given notching fraction, the fraction of beam loss during acceleration that can be tolerated is:

$$f_A = \frac{P_L - \left(N_{ext} E_n R + P_L\right) f_n}{N_{ext} E_A R + P_L}$$

- Assuming a guassian profile as a simple approximation, the amount of beam in the halo that is outside the aperture is:

$$f_h = e^{-3\frac{A}{\varepsilon 95}}$$

Booster Performance

- The amount of beam that is permitted to be in the halo is:

$$f_h = \frac{\Delta N_A}{2\left(N_{ext} + \Delta N_A\right)} = \frac{f_A}{2\left(1 - f_n\right)}$$

- The aperture required is :

$$A = \frac{S_f \varepsilon_{95}}{3} \ln\left(\frac{2\left(1 - f_n\right)}{f_A}\right)$$

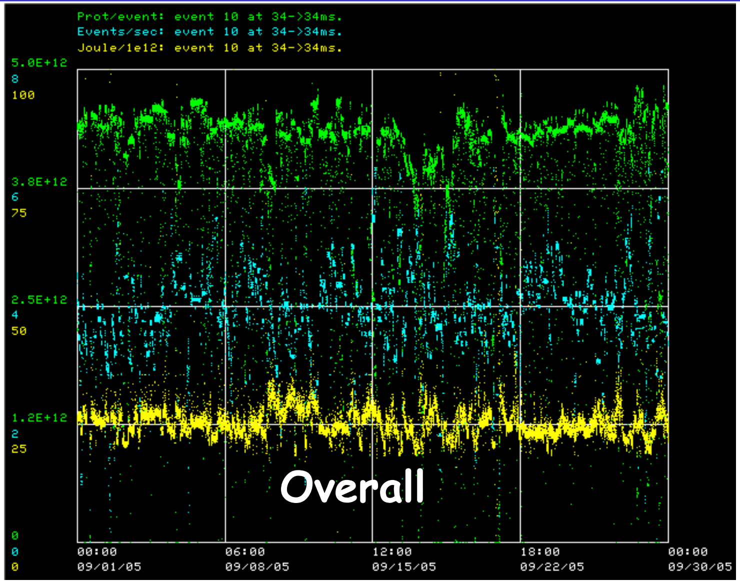
- The half-aperture of the magnets is proportional to
  - The transverse acceptance,
  - The momentum acceptance
  - The closed orbit displacement

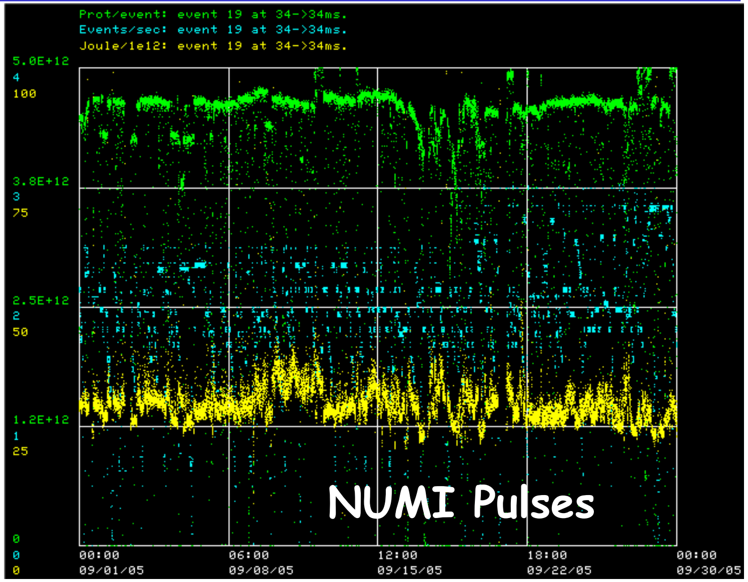
$$\Delta x = \sqrt{\frac{A_n}{\beta\gamma}\beta_{max}} + \frac{\Delta p}{p} D_{max} + \text{c.o.d.}$$

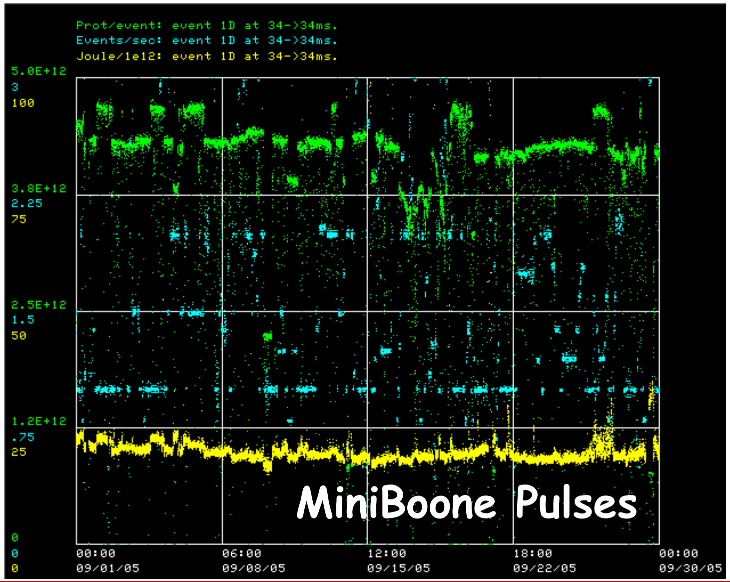
- Compare designs with the same space charge tune shift

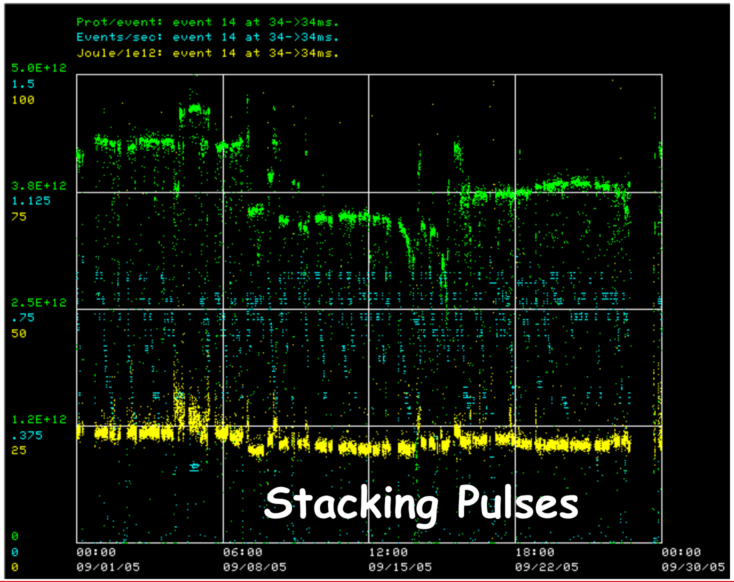
$$\varepsilon_n \propto \frac{N_{inj}}{\beta\gamma^2 \Delta\nu}$$

Booster Performance Sept. 2005









Booster Throughput Scenarios

- The vertical aperture in the present Booster is
  - 1.64 inches for the F magnets
  - 2.25 inches for the D magnets
- The horizontal good field aperture is
  - 4.3 inches for the F magnets
  - 3 inches for the D magnets
- The RF cavities in the Booster are located between two D magnets
  - The horizontal beta function is at a minimum
  - The vertical beta function is a maximum.
  - The RF cavity aperture is 2.25 inches.
- To increase Booster throughput, we have three knobs available
  - Increase beam power lost in the Booster tunnel
  - Increase the effective Booster aperture (or decrease the closed orbit distortion tolerance)
  - Decrease the amount of beam to other programs

Scenarios

- Present
  - Constraints
    - Cycle time – 2.6 Seconds
    - C.O.D 10 mm
    - Loss 440W
    - Booster Notching - 7 / 84 bunches
  - Collider Slip Stacking - 2 batches
  - NUMI – 5 batches
  - MiniBoone – 2e16protons/hr
- NUMI only
  - Constraints
    - Cycle time – 1.5 Seconds – using the Recycler for slip stacking
    - C.O.D 6 mm - **A BIG DEAL – part of the Proton Plan**
    - Loss 440W
    - Booster Notching - 4 / 84 bunches – **A BIG DEAL - part of the Proton Plan**
  - NUMI – 12 batches @ 4.8e12 protons/batch

Scenarios

- NUMI and 4/23 batches to KOPIO
  - Accelerator cost not including slow extraction ~10-12 M$
  - Constraints
    - Cycle time – 1.5 Seconds
    - C.O.D 6 mm
    - Loss 550W
    - Booster Notching - 3 / 84 bunches
      - Improvement comes because notching is not needed for momentum stacking KOPIO beam
  - NUMI – 12 batches @ 4.8e12 protons/batch
  - KOPIO – 4.6e16protons/hr
- NUMI and 8/23 batches to KOPIO
  - Constraints
    - Cycle time – 1.5 Seconds
    - C.O.D 6 mm
    - Loss 600 W
    - Booster Notching - 2.4 / 84 bunches
      - Improvement comes because notching is not needed for momentum stacking KOPIO beam
  - NUMI – 12 batches @ 4.8e12 protons/batch
  - KOPIO – 9.2e16protons/hr

Scenarios

- New Booster in the Debuncher tunnel
  - Accelerator cost not including slow extraction ~80 M$
  - NUMI and 8/23 batches to KOPIO
    - Constraints
      - Cycle time – 1.5 Seconds
      - C.O.D 10 mm
      - Loss 440 W
      - Booster Notching - 2.4 / 84 bunches
    - NUMI – 12 batches @ 8.7e12 protons/batch
    - KOPIO – 9.2e16protons/hr

Booster Throughput Scenarios

Parameter	Present	NUMI 1	N +.18K	N+.36K	NB N+.36K	
Slip Stack Final Intensity	6.9	0	0	0	0	$x10^{12}$
NUMI Final Intensity	22	55	55	55	100	$x10^{12}$
MI Cycle Time	2.6	1.5	1.5	1.5	1.5	Sec
Slip Stack Batches	2	0	0	0	0	
NUMI Batches	5	12	12	12	12	
Slip Stack Efficiency	88	100	100	100	100	%
NUMI Efficiency	95	95	95	95	95	%

Parameter	Present	NUMI 1	N +.18K	N+.36K	NB N+.36K	
Booster Flux	6.38	13.89	18.53	23.15	42.09	$x10^{16}$/Hr
Collider Flux	1.09	0.00	0.00	0.00	0.00	$x10^{16}$/Hr
NUMI Flux	3.21	13.89	13.89	13.89	25.26	$x10^{16}$/Hr
NUMI Beam Power	162	704	704	704	1280	kW
KOPIO/MiniBoone Flux	2.08	0.00	4.64	9.26	16.83	$x10^{16}$/Hr

Booster Intensity Requirements

Parameter	Present	NUMI 1	N +.18K	N+.36K	NB N+.36K	
Extraction Intensity	4.43	4.82	4.82	4.82	8.77	$x10^{12}$
Rep. Rate	4	8	10.67	13.33	13.33	Hz
Average Beam Power Lost	440	440	525	600	440	Watts
Notch Bunches	7	4	3	2.4	2.4	
Notch Energy	450	450	450	450	450	MeV
Acceleration Loss Energy	1050	1050	1050	1050	1050	MeV
Injection Energy	400	400	400	400	400	MeV
Allowed Tune Shift	0.47	0.47	0.47	0.47	0.47	
Bunching Factor	2	2	2	2	2	

Parameter	Present	NUMI 1	N +.18K	N+.36K	NB N+.36K	
Acceleration loss	8.7	4.1	4.1	4.0	0.9	%
Efficiency	83.0	91.1	92.4	93.2	96.2	%
Injection Intensity	5.3	5.3	5.2	5.2	9.1	$x10^{12}$
Norm. Emittance at Inj	11.4	11.3	11.2	11.1	19.5	π-mm-mrad
Norm Acceptance at Inj	18.9	23.5	23.4	23.4	56.5	π-mm-mrad

Booster Aperture Requirements

Parameter	Present	NUMI 1	N +.18K	N+.36K	NB N+.36K	
F magnet β_x	33	33	33	33	15	m
F magnet β_y	14	14	14	14	20	m
F magnet D_x	3	3	3	3	2.5	m
D magnet β_x	14	14	14	14	15	m
D magnet β_y	22	22	22	22	20	m
D magnet D_x	2.5	2.5	2.5	2.5	2.5	m
Momentum Acceptance	0.4	0.4	0.4	0.4	0.4	%
Misalignment & c.o.d.	10	6	6	6	10	mm

Parameter	Present	NUMI 1	N +.18K	N+.36K	NB N+.36K	
F Aperture Width	2.81	2.88	2.88	2.88	3.06	in
F Aperture Height	1.66	1.65	1.65	1.65	3.02	in
D Aperture Width	2.06	2.05	2.04	2.04	3.06	in
D Aperture Height	1.98	2.01	2.01	2.01	3.02	in

Summary

- To run NUMI only with slip stacking in the Recycler we need to
  - Decrease the closed orbit distortion by 40% from present
  - Decrease the notching loss by 43% from present
- To run NUMI and KOPIO at 4.6e16 protons/hour:
  - Decrease the closed orbit distortion by 40% from present
  - Decrease the notching loss by 43% from present
  - Increase the permitted loss in the Booster tunnel by 20% from present
  - KOPIO spill length 82% of cycle
- To run NUMI and KOPIO at 9.3e16 protons/hour:
  - Decrease the closed orbit distortion by 40% from present
  - Decrease the notching loss by 43% from present
  - Increase the permitted loss in the Booster tunnel by 36% from present
  - KOPIO spill length 64% of cycle
- With a new Booster with an apeture of 3" instead of the present 1.65" it is possible to provide
  - NUMI with 1.3 MW
  - KOPIO with 16.8e16 protons/hour
    - 130 hrs/week
    - 45 weeks/ year
    - 9.8e20 protons/year